Implementing a Near-Optimal Optical Receiver for Inter-Planetary Communication

Completed Technology Project (2012 - 2016)

Project Introduction

Proposal Objective: Interplanetary communications signals are inherently weak at the receiver. In fact, for a desired data rate the received optical pulses may contain less than even a single photon. By exploiting both a novel optical receiver architecture and a newly demonstrated quantum switch, I propose to design, construct, and characterize a proof-of-principle implementation of a near-optimal optical transceiver suitable for Earth-Mars communications. Key Methods and Techniques: This proposal relies on two novel discoveries: (1) a new receiver architecture, recently proposed by Guha [1], which allows near-optimal communications using individual pulses which each contain far less than a single photon, and (2) an ultra-fast, low-loss, coherent, single-photon optical switch - exactly the type of revolutionary quantum switch recently developed in the Kumar group [2,3]. This proposal's key methods and techniques involve the successful exploitation of both innovations. Unlike typical receiver architectures, the Guha receiver assumes that loss has degraded a transmitted signal to the point where each transmitted pulse contains less than a single photon. By encoding the data to be transmitted into a large number of these very weak pulses, each in their own spatial mode, and then combining these many weak pulses into a single pulse bright enough to be detected, the Guha receiver can approach the optimal communications rate. This increase in system capacity is known as superadditivity [4]. Although the Guha receiver, in principle, allows for increased capacity there are practical problems with implementing a multi-spatial-mode inter-planetary communications system. In an Earth-Mars communication system, for example, any distinct spatial modes at the transmitter will completely overlap by the time the signal reaches the receiver. Fortunately, many of these problems can be avoided by redesigning the Guha receiver as a temporally, rather than spatially encoded architecture. Implementing the Guha architecture for temporally encoded signals requires a device which can manipulate, with very low loss and at very high speeds, the individual temporal modes of a single photon. In other words, a quantum optical switch is needed. My group has recently demonstrated just such an all-optical, ultra-fast (200-ps switching window), low-loss (1.5dB), high switching contrast (120:1) device [2-3]. This single photon switch is a nonlinear optical loop mirror whose reflectivity is controlled by a separate pump pulse. I propose to combine multiple switches in a temporal Guha architecture in order to implement a proof-of-principle near-optimal optical receiver suitable for Earth-Mars communications. Significance of Proposed Research: Deep-space communications involve extremely high loss. While signal strength can be recovered by increasing detection time, this strongly limits the data rate. However, a recently proposed joint detection receiver has the potential to dramatically increase these rates, approaching the Holevo limit even when each transmitted pulse, after an enormous transmission loss, contains far less than a single photon. I propose to construct a proof-of-principle implementation of a modified Guha receiver using ultra-fast, low-loss, single photon switching technology. If successful, this project could lead to the

Project Image Implementing a Near-Optimal Optical Receiver for Inter-Planetary Communication

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Organizational Responsibility

Responsible Mission Directorate:

Space Technology Mission Directorate (STMD)

Responsible Program:

Space Technology Research Grants

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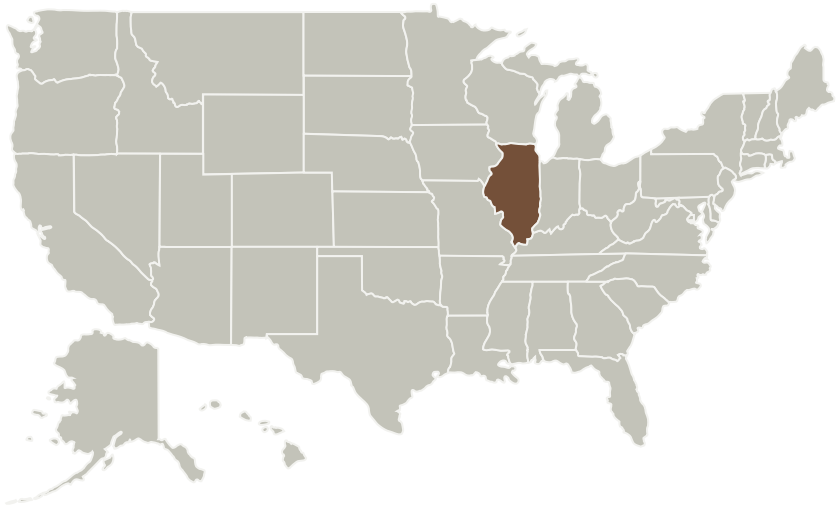
deployment of high-rate communications systems for future NASA missions.
References: [1] S. Guha, Phys. Rev. Lett. 106, 240502 (2011). [2] M. Hall et al., Phys. Rev. Lett. 106, 053901 (2011). [3] M. Patel et al., IEEE Summer Topical Meeting Series, p. 16-17, (July 2011). [4] M. Sasaki et al., Phys Rev. A., 54, 1869 (1996).

Anticipated Benefits

Deep-space communications involve extremely high loss. While signal strength can be recovered by increasing detection time, this strongly limits the data rate. However, a recently proposed joint detection receiver has the potential to dramatically increase these rates, approaching the Holevo limit even when each transmitted pulse, after an enormous transmission loss, contains far less than a single photon. I propose to construct a proof-of-principle implementation of a modified Guha receiver using ultra-fast, low-loss, single photon switching technology suitable for Earth-Mars communications. If successful, this project could lead to the deployment of high-rate communications systems for future NASA missions.

Primary U.S. Work Locations and Key Partners



Organizations Performing Work	Role	Type	Location
Northeastern University(NEU)	Supporting Organization	Academia	Boston, Massachusetts

Project Management

Program Director:
Claudia M Meyer

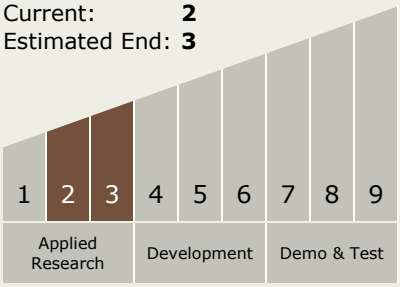
Program Manager:
Hung D Nguyen

Principal Investigator:
Gregory Kanter

Co-Investigator:
Timothy Rambo

Technology Maturity (TRL)

Start: **2**
Current: **2**
Estimated End: **3**



Technology Areas

Primary:

- TX05 Communications, Navigation, and Orbital Debris Tracking and Characterization Systems
  - TX05.5 Revolutionary Communications Technologies
    - TX05.5.2 Quantum Communications

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Primary U.S. Work Locations
Illinois

Images

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Project Image Implementing a Near-Optimal Optical Receiver for Inter-Planetary Communication
(https://techport.nasa.gov/image/1779)

Project Website:

https://www.nasa.gov/directorates/spacetech/home/index.html